Some Nutritional Characteristics of Corn.

J. T. WILLARD, Kansas State Agricultural College.

Paper read before the Kansas Academy of Science, January 15, 1916.

The origin of Indian corn or maize is buried in the silence of milleniums of the unrecorded history of man and his environment. It has been a cultivated captive so long, and has changed so much under restraint and domestication, that its original wild form is now extinct or unrecognizable. The earliest explorers of the Western World found it under extensive cultivation on both continents, from the valley of the La Plata in the south to that of the St. Lawrence in the north. According to Indian legends it was the direct gift of the Great Spirit, and it is certain that it was part of the Red Man's endowment of his conquerors.

Maize seems to have been taken to Spain about 1500 A. D. and to have spread rapidly from that country to others bordering the Mediterranean Sea in both Europe and Africa. It was introduced into West Africa by the Portuguese, and the East Indies are indebted for it to the same adventurous voyagers. It spread so rapidly from its several points of introduction that some have even believed that it was indigenous to the Old World. Careful investigation, however, has shown that it was unknown there previous to the discovery of America. Its wide cultivation within a century thereafter is testimony to its excellence. It was welcomed and appropriated by prince, peasant and savage. Its beauty of figure, foliage, silk and tassel would give it a place in an artist's garden even though it carried no appeal to the economist. Its five hundred-fold yield places it at the front as a food producer wherever it can be grown, and in number and variety of food products for man and beast it excels all other cereals. From the moment when it thrusts its ivory plumule from the darkness of earth to the brightness and warmth of the spring sun to that in which its buffeted and broken body yields itself reluctantly to the mother soil, it is the emblem of sturdy determination and endurance, and the embodiment of the beauty of Youth, the unstinted service and generosity of Maturity and the resignation of Age.

The nutritional characteristics of any food depend fundamentally upon its composition and the chemical constitution of its components. As estimation of all values depends upon comparison, and nothing can be measured except by its contrast with or resemblance to something else, data will be presented for some other foods to a certain extent at the same time that they are shown for corn.

The composition of a food substance if completely known would show the percentage of each chemical compound present, and complete information concerning these compounds would include their inner constitution, or the arrangement among themselves of the chemical elements of

NOTE.—For many years it has been the practice of the Kansas Academy of Science, at its annual meeting, to devote one session principally to a lecture designed to be of general interest and to bring the work of the members of the Academy to the attention of the general public. The lecture at the meeting held January, 1916, was given by Prof. J. T. Willard, of the Kansas State Agricultural College, who, as professor of chemistry and chemist of the Agricultural Experiment Station, has had opportunity to give considerable study and experimentation to corn and its products. In order to give the lecture a wider circulation in the state the Academy voted to have it printed as a bulletin. The Academy plans to issue bulletins of a scientific character and of general public interest from time to time as means and material permit.

which the compounds consist. The physiological relations of these compounds must also be known for any adequate study of their relation to nutrition; that is, we must know how they are affected by the digestive agents, and what possibilities the absorbed products of digestion present to metabolism, the complex physical and chemical processes that accompany the activities of living things. It need scarcely be said that we are not in possession of such complete knowledge of even one food substance. The purpose of investigations in nutrition is to explore unknown or little known areas in this field, in the hope that something will be found that is of benefit to man in one way or another.

The simplest expression of the composition of a food substance includes the proximate principles water, ash, protein, carbohydrates, and fat. This is of much service in spite of its incompleteness and indefiniteness. Better statements embody more details cencerning the ash, protein, carbohydrates or fat. Nearly always in the case of cattle feeds the fiber of the carbohydrates is separately stated, and the remainder placed under the heading of nitrogen-free extract, which really includes several classes of substances. The protein of the conventional statement is also a complex mixture of compounds, varying greatly in value, and in the mixtures found in different foods differ greatly from each other. The ash is the residue left after burning a food as completely as possible at a low temperature and is entirely different from the substances present originally. It contains metals, phosphorus, sulphur, etc., which were to a considerable extent constituents of organic substances in the food. The relative amounts of these elements, as well as the total quantities, give an insight into the dietetic adaptability of a food. These data can be learned only by detailed analysis of the ash.

The fat of foods as ordinarily determined is also an impure extract containing substances that are not fats, and usually several different fats. This sketch may serve to give an idea of the extreme complexity of foods and of the total inadequacy of the usual simple statements of their composition.

One of the most noticeable nutritional features of corn is the fact that both the grain and the stalk possess definite value. This is also true of wheat, oats and barley, but in these cases the straw is of little value. With the sorghums, to which belong not only sweet sorghum, but kafir corn, milo maize, feterita, etc., there is also notable value in both the grain and the stalk.

The corn plant may be utilized in several fundamentally distinct ways which may be mentioned without detailed consideration. If the corn is planted chiefly for grain and is permitted to come to maturity and the grain is husked out, the remainder is properly designated as corn stover, although often called corn fodder. Technically corn fodder is a crop produced by thicker planting, from which the ears are not removed. Such a crop is also available for conversion into excellent silage. In addition to these standard means of utilizing the stalks of corn, to a certain extent corn stover is finely shredded and converted into a product which can be conveniently stored under cover and fed to stock at better advantage, in that it is consumed more completely, and handled more conveniently.

Table I.—Percentage Composition of some Important Roughages.

	Water.	Ash.	Protein.	Fiber.	Starch, sugar, etc.	Fat.
Corn stover	40.5	3.4	3.8	19.7	31.5	1.1
Corn fodder	42.2	2.7	4.5	14.3	34.7	1.6
Corn silage	73.6	2.1	2.7	7.8	12.9	0.9
Sorghum fodder	41.7	3.0	3.2	17.0	32.2	2.9
Sorghum silage	76.1	1.1	0.8	6.4	15.3	0.3
Kafir-corn fodder	52.1	2.4	2.5	21.0	20.1	1.8
Kafir-corn silage	67.2	2.9	2.1	11.2	15.2	1.4
Wheat straw	9.6	4.2	3.4	31.1	43.4	1.3
Prairie hay	9.2	7.8	6.2	34.1	39.9	2.8
Millet hay	14.0	7.9	10.6	28.7	37.1	1.7
Timothy hay	13.2	4.4	5.9	29.0	45.0	2.5
Clover hay	15.3	6.2	12.3	24.8	38.1	3.3
Alfalfa hay	8.1	8.8	14.6	28.9	37.4	2.1

Table I shows the composition of several important rough feeds, in which those from corn are brought into comparison with those from other plants. Differences in the moisture content make direct comparison difficult. As a practical question much depends upon the care with which the several fodders and hays are harvested and preserved. Corn fodder and stover are especially subject to damage by wind and water, and while when in prime condition are valuable feeds, are likely to be rather inferior. There are no great differences between corresponding products from corn, sorghum and kafir corn. Reduced to the same moisture content, first-class corn fodder compares not unfavorably with prairie hay and timothy, but is distinctly inferior to clover hay and alfalfa hay.

Table II.—Percentage Composition of some Cereals and Products.

	Water.	Ash.	Protein.	Fiber.	Starch, sugar, etc.	Fat.
Corn, dent	10.6	1.5	10.3	2.2	70.4	5.0
Flint	11.3	1.4	10.5	1.7	70.1	5.0
Sweet	8.8	1.9	11.6	2.8	66.8	8.1
Pop	10.7	1.5	11.2	1.8	69.6	5.2
Green corn	75.4	0.7	3.1	0.5	19.2	1.1
Corn meal, bolted	12.5	1.0	9.2	1.0	74.4	1.9
Corn bran	9.4	1.2	11.2	11.9	60.1	6.2
Hominy	11.8	0.3	8.3	0.9	78.1	0.6
Wheat	10.5	1.8	11.9	1.8	71.9	2.1
Wheat flour	12.4	0.4	12.0	....	74.0	1.2
Wheat bran	11.9	5.8	15.4	9.0	53.9	4.0
Rice, unpolished	11.9	1.2	8.0	0.9	76.0	2.0
Rice, polished	12.4	0.4	7.4	0.2	79.2	0.4
Rice polishings	10.8	4.8	11.9	3.3	62.3	7.2
Kafir corn	9.9	1.6	11.2	2.7	71.5	3.1
Oats	10.4	3.2	11.4	10.8	59.4	4.8
Rye	8.7	2.1	11.3	1.5	74.5	1.9
Barley	10.8	2.5	12.0	4.2	68.7	1.8
Millet seed	12.1	2.8	10.9	8.1	62.6	3.5

Table II gives the composition of different kinds of corn and some products, and for comparison that of several other cereals and products. These are the principal grains of the world. The relative rank of these is of some interest. There can be little doubt that rice is produced in greater quantity than any other, though statistics are not as available from the heavy rice-producing countries as they are from those which produce most of the wheat, corn, barley and oats. Taking the average

production for the years 1904 to 1913* inclusive, wheat has yielded 3,487,008,100 bushels, while the figures for corn for the same period are 3,662,229,400 bushels. The greatest yield of wheat in any one year was obtained in 1913, and was 4,128,711,000 bushels. The greatest yield of corn was in 1912, when it reached 4,371,888,000 bushels. It will be noted that in the average and in the maximum corn outranks wheat if the yield be stated in bushels. However, since wheat weighs sixty pounds to the bushel, while corn weighs only fifty-six, the weights for wheat are somewhat larger. The yield of oats is also about the same in bushels but much less in weight, while rye and barley each furnish about one-half as much. The fact that of the enormous total production of corn three-fourths is harvested in this country is ample basis for the saying, "Corn is king." Corn is easily the leading cereal of this country, and no other country possesses so large an area of soil adapted to corn culture. Argentine is next to us in production, but follows at a long distance. Hungary, Roumania and Italy are third, fourth and fifth in rank. The study of the nutritional value of corn is a problem commensurate in its importance with the magnitude of the world yield.

If the composition of corn be compared with that of other cereals, we may note that it is richer in fat than is wheat, and is somewhat lower in protein and carbohydrates. Comparing bolted corn meal with wheat flour it is seen that the superiority as to fat possessed by corn is not conferred upon corn meal. This is because the germs are largely removed by the bolting, and these carry more than three-fourths of the total fat of the grain. Corn meal furnishes twice as much ash as does wheat flour, and a somewhat greater quantity of carbohydrates. When we compare corn or corn meal with the polished rice of commerce, we see that in respect to all constituents except carbohydrates, corn is superior. Kafir corn, which fairly represents the sorghums, is also of special interest in this state, and is seen to be strikingly similar to corn in composition, but is poorer in fat. On the whole it may be noted that the seeds of all of these related plants have a strong general resemblance in composition.

The composition and physical character of the grain of different varieties of corn vary greatly. Sweet corn is one of the most delicious of vegetables when cooked in a green state, and its attractiveness is not altogether destroyed by canning or drying. The canning of sweet corn constitutes an extensive industry in this country, and the product adds much to the diversity of the bill of fare throughout the year. Dried sweet corn has a more delicate flavor, though of harder texture. Popcorn either with or without additions is a dainty of no mean order. However important these varieties of corn might otherwise seem, they are depressed into insignificance when brought into contrast with their coarser but more luxuriant brother, common field corn.

In utilizing the corn grain there is opportunity for still greater diversity of products than is the case with the stalks. The corn kernel consists of three well-defined parts, namely, the thin wall or bran surrounding the remainder of the kernel; the germ or embryo; and the endosperm, which constitutes by far the greater part by weight. The

* Year Book U. S. Dept. of Agr., 1914.

endosperm often shows distinct parts, one of which is of a clear horny texture, while the other is white and starchy in appearance. The physical characteristics, and to a considerable extent the chemical characteristics, of the corn kernel vary with differences in the relative amounts of the horny and the starchy portions of the endosperm. Other parts of the kernel which may be considered separately are the tip, by which it is attached to the cob, and the starch which is associated with the tip. Table III shows the percentage composition of corn and the distribution of its constituents among the several parts. The figures are reduced to a water-free basis and are given by Burtt-Davy,* who put them in this form from the results published by Hopkins.†

Table III.—Percentage Composition of Corn and Distribution of the Constituents Among the Parts. Dry Basis.

	Ash.	Protein.	Carbo-hydrates.	Fat.
Corn kernel	1.52	11.28	82.49	4.67
Tip cap	.02	.10	1.28	.02
Hull	.05	.24	5.48	.05
Horny gluten	.16	2.46	7.96	.55
Horny starch	.09	4.25	38.61	.09
Crown starch	.05	1.36	15.92	.05
Tip starch	.04	.70	9.36	.06
Embryo	1.11	2.17	3.88	3.85

Table IV.—Percentage Composition of Feeds Obtained From Corn Grain.

	Water.	Ash.	Protein.	Fiber.	Starch, sugar, etc.	Fat.
Corn meal, feed	15.0	1.4	9.2	1.9	68.7	3.8
Corn germ	10.7	4.0	9.8	4.1	64.0	7.4
Corn germ meal	8.6	2.4	21.7	8.8	47.3	11.2
Corn bran	9.4	1.2	11.2	11.9	60.1	6.2
Gluten feed	9.2	2.0	25.0	6.8	53.5	3.5
Gluten meal	9.6	0.7	29.4	1.6	52.4	6.3
Hominy feed	9.6	2.7	10.5	4.9	64.3	8.0

Study of Table III gives one an excellent idea of the characteristics of the different parts of the corn kernel and shows the basis for various chemical food products. The richness of the embryo in ash and fat is quite marked. In the manufacture of corn starch the embryo is separated, and with it the ash and fat are carried to a large extent. The embryo is also rich in protein. It may also be seen that the horny gluten carries much less carbohydrates in proportion than does the horny starch, while it is materially richer in ash. The figures are precentages based on the whole grain.

There are numerous food substances which consist of one or more parts of the corn grain that have been separated by mechanical processes. Corn meal is made by removal of the hulls and most of the germs, and finer grinding. Samp, hominy and grits are products in which the body of the corn kernel is much coarser than is corn meal, but from which

*Maize: Its History, Cultivation, Handling and Uses.

† Bull. 55, Ill. Agl. Expt. Station, The Chemistry of the Corn Kernel.

the hulls and germs are also absent. There are numerous breakfast foods consisting wholly or partly of some corn product. Corn flour is a fine starchy product obtained from corn and which may to a certain extent be mixed with wheat flour without unduly impairing the gluten-producing power of the wheat flour upon which its use in making yeast bread depends.

The proteins of corn do not, as do those of wheat, possess the power to form an adhesive glutinous mass when mixed with water, and hence cannot be leavened by yeast, or by baking powders to any great extent. The food use of corn and its products is thus restricted in some degree, but this very lack gives them a greater usefulness in certain other directions, such as in griddle cakes, puddings and mush.

Twenty million bushels of corn are used annually in the United States in the manufacture of alcohol and alcoholic beverages, and in this connection large quantities of by-products are obtained which are used in feeding cattle, milk cows and swine. Three million bushels of corn, rye and barley were used by a single Peoria firm in one year in the manufacture of denatured alcohol.

The manufacture of starch from corn is one of our great industries. This is used in part as such for food, and for stiffening goods, and largely for the manufacture of a number of substances produced by the glucose factories. Starch has a highly complex molecular structure, and in the presence of water, and under the stimulus of enzymes, acids or other agents it may undergo changes in which water enters into combination, and an extensive series of products is formed. The chemistry of these cannot be entered into at this time in any detail. Suffice to say that the articles of commerce are for the most part mixtures containing several of these alteration products of starch, the relative quantities of which differ in the different commercial substances. These alteration products are soluble starch, dextrines, maltose, and dextrose or grape sugar. The nature of the commercial product obtained depends on the degree of completeness to which the chemical change is carried, grape sugar being the final product, the dextrines and maltose marking stages in the transformation. After the process has gotten well under way all of the substances named are present, but as the change proceeds the dextrines diminish in quantity while grape sugar increases. By continuing the action long enough the total product finally consists practically of grape sugar only.

Another name for grape sugar is glucose, but in commerce the name glucose is applied to intermediate products that consist largely of dextrines, and are produced in the form of sirups from which grape sugar does not crystallize out. Commercially the final product is called grape sugar, and this is obtained as a solid substance. If this grape sugar be heated gently it is changed to caramel, which has a brown color and a characteristic flavor.

The personal experiences of nearly all of us are such that a mere naming of starch and these alteration products is enough to give a strong impression of the importance of corn as a source of accessory as well as staple food substances. Glucose sirup or corn sirup is extensively consumed, usually mixed with other sirups which give it characteristic

flavors. Karo and Mary Jane are examples of such products. Glucose, grape sugar and caramel are all extensively used in confectionery, and glucose is a constituent of many commercial jellies, preserves, etc., being used to give body, as it is itself deficient in sweetness or other flavor.

When starch is taken into the alimentary tract the digestive enzymes cause it to pass through the same series of chemical transformations that has been described as the result of the glucose manufacturer's art. It is, therefore, obvious that the artificial products are perfectly wholesome. As they come into competition with similar substances in which the sweet taste or sirupy consistence is due to cane sugar, or beet sugar, which are more expensive, it will be seen that food economy is furthered by the use of these glucose products, but that fair trade requires that they be sold for what they are, with no attempt to dispose of them as cane or beet sugar products.

There are several commercial feeds derived from corn, the composition of which is shown in Table IV. The simplest is corn chop, which is coarsely ground corn, and would, of course, have the same composition as does corn. In the production of starch, which is to a large extent manufactured for immediate conversion into glucose, the corn is steeped for some time to soften it, and is then ground in such a way as not to break up the germs and is separated, by means of running water and suitable machinery, into hulls, germs, starch, and protein substances in an impure state. The corn germs are usually separately handled and are ground and pressed to remove the oil, which is an important article of commerce. The residue is sold as corn germ cake, or ground and sold as germ oil meal. The protein substances, if separated and dried, constitute gluten meal, one of the richest of feeds in respect to protein and fat. It is not largely used as such, but is ground together with the hulls or corn bran, and the product is sold under the name of gluten feed, now the largest by-product of the glucose factories.

In the manufacture of hominy and grits the hulls together with some of the starchy substances of the corn grain are combined into a concentrated product known as hominy feed. Corn bran is seldom sold as a separate feed.

Table V.—Mineral Elements of Cereal Products. Percentages in the Dry Substances. Forbes et al.

	Total	Potassium	Sodium	Calcium	Magnesium	Sulphur	Chlorine	Total phosphorus	Inorganic phosphorus	Organic phosphorus
Corn	1.113	.396	.030	.014	.126	.171	.073	.303	.028	.275
Corn meal, bolted	.898	.192	.113	.015	.122	.122	.070	.264	.019	.245
Corn brand	.860	.410	.000	.030	.088	.124	.052	.156	.031	.125
Pearl hominy	.543	.153	.000	.005	.036	.186	.052	.111	.019	.092
Wheat	1.567	.590	.035	.056	.142	.224	.095	.425	.038	.387
Wheat flour	.577	.058	.127	.022	.019	.168	.081	.102	.017	.085
Wheat bran	4.946	1.464	.223	.139	.590	.297	1.000	1.233	.034	1.199
Rice, polished	.367	.040	.032	.009	.028	.114	.040	.104	.003	.101
Rice polishings	4.198	1.279	.124	.030	.741	.189	.151	1.684	.028	1.656
Kafir corn	1.083	.283	.066	.013	.1[illegible]2	.186	.117	.271	.012	.259
Oats	1.611	.460	.184	.112	.130	.214	.077	.434	.059	.375

Table V exhibits the elementary composition of the ash of several cereals and their products as determined by E. B. Forbes and his associates. The figures given under "total" are not comparable with those under "ash" in Table II, as the latter include oxygen that is combined with the other elements. Time does not permit much detailed comparison of the data shown in Table V, but attention may be drawn to a few points. Corn carries only about three-fourths as much total mineral elements or total phosphorus as does wheat or oats, while slightly exceeding kafir corn in these constituents. In calcium it is equal to kafir corn, but wheat has four times as much, and oats eight times as much. In the percentage of magnesium these four grains are almost identical. If now we consider the ratio of calcium to magnesium we find it to be as follows: In kafir corn, 1:11; corn, 1:9; wheat, 1:2.5; oats, 1:1.2. As in the human body the ratio of calcium to magnesium is 1:0.025 or 40:1, and this probably holds approximately for other animals, it will be seen that not only does corn exhibit a very low content of calcium, but that the ratio of calcium to magnesium is far lower than with these other grains, and that all of them provide calcium in much smaller quantities than they do magnesium when compared with the storage needs of a growing animal. Milk contains about eight times as much calcium as magnesium, nearly the reverse of the ratio found in corn.

While corn and its products are very extensively used as human food, corn meal being the cheapest of all food articles, the greatest use of corn is for the feeding of animals. When swine are fed, the cheapest grain is thus transformed into meat by the species that makes the most rapid growth of all domestic animals, and is therefore by the conjunction of these two factors the most economical source of meat that we have, or are likely to have.

Much might be said, if time permitted, on investigations with animals touching the nutritional characteristics of corn and its products. I wish to bring before you part of the results obtained in a series conducted jointly by President Waters and members of the Experiment Station force in the departments of Animal Husbandry and of Chemistry in the Kansas State Agricultural College.

It is a matter of common experience with practical farmers that corn does not seem to be a perfect grain food. Though used extensively with horses, cattle, swine and poultry, it is most satisfactory when accompanied by significant quantities of other feeds. Scientific men have sought to account for this by directing attention to the low ash content of corn, of which mention has been made. Going somewhat deeper, the unbalanced character of corn ash has been noted. In milk, calcium and magnesium are present in the ratio of about 7.6:1, in the animal body the ratio is about 40:1, while in corn grain it is only 0.11:1. Milk may be taken as Nature's guide to the proper relation of the several metals and other food constituents in food for a growing animal, and, tested by that criterion, corn has only about one-seventieth of the calcium that would be necessary to balance the magnesium present. If total solids be considered, it is seen that milk solids contain .770 per cent of calcium and .103 per cent of magnesium, while corn solids contain .014 per cent of

calcium and .126 per cent of magnesium. Compared with milk, corn has more than sufficient magnesium, but should have 55 times as much calcium as it has.

It has been found that in biological processes there is a certain antagonism between calcium and magnesium; that normal functioning requires a proper balance between them, and that presentation of excess of magnesium causes loss of calcium. With these facts in view it may be reasonably suspected that at least a part of the unfavorable results with corn are due to deficient and unbalanced ash.

Another possible explanation of the defective nutritional power of corn may be found in the constitution of its principal protein zein. An understanding of this requires some knowledge of the inner constitution of the proteins. These indispensable and highly complex compounds for many years baffled investigation of their chemical nature, and little real progress was made until about the beginning of this century. It is now known that to a large extent they consist of combinations of molecular nuclei derived from amino acids. These, with nuclei representing other classes of compounds, are linked together to form structures of only partially known and almost inconceivable intricacy. The proteins peculiar to different plant and animal tissues differ in their inner make-up, and to build up any one, in an animal tissue, for example, it is necessary that most of the specific nuclei of the body protein be present in the food protein. To only a limited extent, and in certain lines, is it possible for the tissue to synthesize its own nuclei.

There are about twenty amino acids which are represented in the proteins, and may be produced from proteins by suitable procedure, and in a somewhat loose way may be spoken of as present in the proteins. In digestion the amino acids are produced from the proteins, and are absorbed by the blood and by that channel distributed to all of the tissues of the body. The body organs synthesize their characteristic proteins from the amino acids and other substances, but the extent to which they are able to do this is limited by the amino acids that are present in the relatively minimal quantities. If a certain amino acid is required that is not present no protein can be produced; if it is present in but small amounts, relatively, others present in abundance can be used only to the extent that they are demanded to go with the one present in small amount, and so but little protein can be formed.

Mendel and Fine* have made digestion determinations upon the proteins of corn and have found that they are digested and metabolized somewhat less completely than those from meat. This does not show, however, that corn proteins are utilizable for the same purpose or with the same physiological economy as are meat proteins. The corn kernel† contains several different proteins, the principal ones being zein, which is present to the extent of about six per cent of the corn, and maize glutelin four and one-half per cent. Other proteins aggregate about four per cent. Together these proteins seem to contain nuclei of all of the animo acids, but zein, the most abundant one, is incomplete, glycin,

* Jour. Biol. Chem. X (1911-'12) 345.

† Osborne, Jour. Chem. Soc. XIX; 525. An. Rept. Conn. Agr. Expt. Sta., 1896, p. 391.

lysin and tryptophane being absent. The lack of glycin is believed to be a matter of no consequence, as it can be synthesized from other amino acids. With lysin and tryptophane, however, the case is different. If they are not represented in the proteins of a food, the organism is unable to make good the deficiency. Lysin and tryptophane are represented in all of the principal animal proteins, and, hence, must be supplied in the food proteins if true growth is to take place. It is possible, and indeed quite probable, that the quantities of these supplied by the proteins of corn are insufficient, and that the use of corn in nutrition is limited by these factors.

The experiments conducted at the Agricultural College touching deficiencies of corn have been upon young swine. These animals are well adapted to such tests because of the rapidity of their normal rate of growth, through which dietetic deficiencies would be accentuated, and results manifested more definitely and promptly than with a slow-growing animal. In the latter case a large proportion of the feed would be used in heat production, and elements, or certain molecular groupings presented in smaller quantities, might prove to be adequate because of the greater total quantity consumed for a pound of gain, the body conserving in its added tissue the molecular fragments most restricted in supply, and using the more abundant in the current need for muscle work and heat.

Another advantage of swine for such investigations is the fact that the young are produced in litters, thus making it possible to place in the different lots to be tested, animals of the same age and ancestry, and therefore more nearly alike than can be the case with cattle or horses. Experimental groups can thus be made up that are closely similar in essential respects.

For the last six years the Agricultural Experiment Station of the Kansas State Agricultural College has been conducting experiments in the nutrition of growing pigs with the object of ascertaining the nutritive deficiencies of corn and the means of correcting these. These experiments have been planned jointly by President Waters and the members of the departments of Animal Husbandry and Chemistry. It will not be possible to discuss the entire series, but the one just completed will, I think, be of special interest as determining almost positively some of the nutritional characteristics of corn. Some phases of the experiments of preceding years may also receive notice.

In all these experiments the pigs have been divided into lots of usually three each, the lots being made as nearly uniform as possible in respect to age, lineage and general characteristics of the individuals. Thirty-nine lots have been fed within the six years. This season ten lots were fed, which received the following rations:

(*Rations for ten lots of pigs fed, 1915.*)

Lot 30. Ground corn alone. Nutritive ratio 1:9.

Lot 31. Ground corn + ash. Nutritive ratio 1:9. Ash 2.5 per cent of corn.

Lot 32. Ground corn + defibrinated-blood protein nearly free from ash. Nutritive ratio 1:4.

Lot 33. Ground corn + defibrinated-blood protein nearly free from ash + ash. Nutritive ratio 1:4. Ash 4 per cent of ration.

Lot 34. Ground corn + starch + buttermilk casein + ash. Nutritive ration 1:9. Ash 2.5 per cent of ration.

Lot 35. Ground corn + buttermilk casein + ash. Nutritive ratio 1:3. Ash 2.5 per cent of ration.

Lot 36. Ground corn + buttermilk casein +ash. Nutritive ratio 1:6. Ash 2.5 per cent of ration.

Lot 37. Ground corn + buttermilk casein + ash. Nutritive ratio widened from month to month 1:3-4-5-6-7-8. Ash 2.5 per cent of ration.

Lot 38. Ground corn + egg-white protein nearly free from ash. Nutritive ratio 1:4.

Lot 39. Ground corn + egg-white protein nearly free from ash + ash. Nutritive ratio 1:4.

The ash used consisted of calcium carbonate 92 parts, calcium lactate 8 parts, tertiary calcium phosphate 10 parts, secondary potassium phosphate 37 parts, sodium chloride 20 parts, sodium citrate 15 parts, and ferric citrate 2 parts. Total 184.

Distilled water was used instead of ordinary water.

The purpose of the different lots may be briefly noted. Lot 30 was the fundamental one, the pigs being given ground corn and distilled water only. With this, lots 31, 32, 38, 33 and 39 are to be especially compared.

Lot 31 received the same as lot 30, and in addition an artificial ash consisting of a mixture of ash salts based on one used successfully by Osborne and Mendel,* and which was very similar to Roehmann's successful mixture. The change which we made was to omit magnesium citrate, on the supposition that corn is adequately supplied with magnesium, and to supply a much larger amount of calcium in the form of calcium carbonate.

Lot 32 differed from lot 30 in that in addition to corn and distilled water it received the proteins of defibrinated blood that had been treated especially for the removal of salts. Lot 38 was similar to 32 except that the proteins added were those of egg white freed form ash as nearly as practicable.

The pigs of lots 33 and 39 were given both ash and purified protein in addition to the corn and distilled water.

By comparison of the results of these six lots one learns the results of feeding corn alone, and the effect of supplementing it by ash or protein or both, and may observe the relative effect of proteins from two sources. These proteins are complete in that they furnish all of the required amino acid complexes.

The nutritive ratio of corn is wider than is believed to be best for the nutrition of young growing swine, that is, the carbohydrates are present in too large an amount relatively to the protein, the nutritive ratio being about 1:9. The purpose of lot 34 was to ascertain how pigs would grow on a ration of the same nutritive ratio as corn, 1:9, but which contained casein, a protein that previous experiment had shown to supplement corn perfectly. The casein added was balanced by corn starch. Ash was also supplied this lot.

* Publication No. 156, Carnegie Institution of Washington, Part I, p. 32.

Table showing initial and final weights, in pounds, of pigs in nutrition experiment No. 6, concerning the deficiencies of corn. K. S. A. C., July 3 to December 30, 1915, 180 days.

Lot No.	Individual No.	Initial weights. Individuals.	Initial weights. The lot.	Final weights. Individuals.	Final weights. The lot.	Average monthly gain.	Lot No.	Individual No.	Initial weights. Individuals.	Initial weights. The lot.	Final weights. Individuals.	Final weights. The lot.	Average monthly gain.
	10	28		31				10	28		31		
30	1000	31	76	61	113	2.1	30	1000	31	76	61	113	2.1
	101	17		21				101	17		21		
	110	28		32				1110	23		164		
31	1001	29	78	36	98	1.1	34	1100	31	72	184	494	23.4
	102	21		30				121	18		146		
	1101	29		108				2002	20		208		
32	1010	25	75	79	248	9 6	35	2	19	59	234	602	30.2
	112	21		61				111	20		160		
	2001	30		192				2010	23		229		
33	11	18	71	161	525	25.2	36	12	21	61	171	600	29.9
	201	23		172				1011	17		200		
	1003	26		59				2000	18		207		
38*	......	....	55	....	139	8.4	37	1	22	61	222	609	30.4
	3110	29		80				1012	21		180		
	1002	24		183									
39*	......	....	57	....	385	32.8							
	2110	33		202									

*August 2 to December 30, 1915, 150 days.

Lots 35, 36 and 37 were introduced for the purpose of still further guiding our conclusions by knowledge concerning the possible influence of nutritive ratio on the results that might be obtained. Corn, buttermilk casein, and ash were used in each case. In lot 35 the nutritive ratio of 1:3 was narrow, that is, it was rich in protein, that of lot 36 was 1:6, intermediate between lots 34 and 35, while that of lot 37 was narrow at the beginning of the trial and widened month by month.

In lots 34, 35, 36 and 37 the same food substances were used, but in different relative amounts. The substances were known to be adequate for nutrition, but the most suitable relation among them might well be an important question for investigation, and the lots furnished a valuable background for judgment concerning the other lots.

Table VI summarizes some of the more interesting points concerning the growth of these pigs. As the experiment has just been concluded the chemical results are not at hand as yet. The gains made by the several lots show unmistakably their general nutritional condition. The pigs were about two and one-half months old when they were put on experiment, and were of nearly the same age. Each pig was fed what it would eat up clean. Of course those that made the highest gains did so by consuming the most feed.

The corn-fed lot gained very little, though the largest pig greatly surpassed the others in its own lot, and also those in the corn-and-ash lot, No. 31. While it gained thirty pounds, the average total gain of the other five referred to was only five and four-tenths pounds. It is perfectly evident that the addition of ash only to the corn did not completely supplement it.

Comparison of lot 30 with lots 32 and 38 shows that the blood and the egg protein when not accompanied by ash did not enable normal growth to be made, although the results were better than those shown by ash alone, the average gain per day of each of the six pigs being about three-tenths of a pound.

Consideration of lot 33 shows that here, where both ash and blood protein were added to corn, a very good growth was obtained, it being about five-sixths of a pound per day per pig. In lot 39, in which egg-white proteins were added with ash, each of the pigs gained over a pound a day for the 150 days that they were in the experiment, and made the most rapid growth of any lot in the test.

Valuable information is contributed by lots 34, 35, 36 and 37, all of which received corn, and commercial buttermilk casein, and in which lot 34 was also fed corn starch in order to reduce the nutritive ratio to that of corn. Lot 34 was notably inferior to the others, and shows that a nutritive ratio as wide as that of corn is not suitable for young growing pigs, even though it contains a supply of so admirably adapted a protein as is milk casein. The other three lots are not very different in outcome, though up to the last three weeks lot 37 was distinctly in the lead. In this lot the nutritive ratio was narrow at first, when the young pigs were actively forming protein in their bones, glands, muscles and connective tissue, and as these fundamental cellular structures came to be supplied, and growth consisted more and more in the storage of fat, the relatively reduced supply of protein was entirely adequate. The excellent showing made by these pigs throughout the trial confirmed the scientific judgment which anticipated the results obtained.

On the whole we may conclude from this experiment: (1) That for young pigs, corn is deficient in ash; (2) that it is also deficient in protein; (3) that the protein of corn is defective in character. That additional ash is needed is established by the facts that when pure proteins of complete amino-acid constitution, derived from blood and from eggs, are fed with corn, they are ineffective unless accompanied by additional ash. The deficiency of total protein is shown by the superior results obtained in lots 35, 36 and 37 over those shown by lot 34 with its lower supply of the same protein. The fundamentally defective character of the corn proteins is proven by the greatly superior results shown by lot 34 over lot 30. In these two lots the relative amount of protein in the ration was the same, but the presence of the complete protein, casein, determined a very good growth in lot 34, while in lot 30 two of the animals barely lived through the experiment, and the others made but a small growth.

A very interesting experiment was conducted at the Wisconsin Agricultural Experiment Station on sixteen grade Shorthorn heifer calves, divided into four lots of four each, as nearly equal in weight as possible.* The plan of the experiment included subjecting these animals to all of the strain naturally coming to the species, including reproduction and lactation. It was therefore continued through four years at least, beginning May 31, 1907. Through this length of time one lot was fed

* Research Bull. No. 17, Wis. Agr'l Expt. Sta.

wholly upon the products of the corn plant, another upon products of wheat plant, a third upon products of the oat plant, and the fourth upon a mixture of equal quantities of products from the three plants, corn, wheat and oats. The corn ration consisted of corn stover, corn meal and gluten feed; the wheat ration of wheat straw, wheat meal and wheat gluten; the oats ration of oat straw and rolled oats. The feeds were balanced to a nutritive ratio of 1.8, that is, of the total energy available to the animals about one-ninth, or about eleven per cent, was from protein.

The results of the trial cannot be given in anything but outline at this time. It was found that there was nothing in the rates of growth or the total gains in live weight to indicate that one ration was very much superior to another. At the end of two years, however, there was a marked difference in the appearance of the corn lot and the wheat lot, the other two being intermediate. The corn-fed animals looked smooth of coat, fuller through the barrel and were in a better state of nutrition than any of the others. The wheat-fed animals had rough coats, were gaunt and thin in appearance, and small of girth and barrel, and to the eye of the practical man in a lower state of nutrition.

The greatest differences in the lots were shown in the performance of the reproductive function. Within the last two years of the experiment the four cows of the corn-fed lot produced eight strong and vigorous calves, all of which lived. With the wheat-fed lot, six weak calves were produced. One was born dead, the others died within a few hours. The second year one of the cows died of anthrax and another by accident, and on this account there were but six calves in the lot. The oats-fed cows produced one dead calf, one so weak that it died on the third day, and six that, though of varying degrees of weakness at birth, were able to live by the aid of special nursing in some cases. The cows receiving the mixture ration gave birth to two dead calves, one that lived only six hours, and three that lived, although weak or only fairly strong. One of these cows was not with calf the second year, and one aborted the first year by reason of an accident.

This highly suggestive experiment, only the main features of which have been touched at all, shows that the entire corn plant was markedly superior to the oat plant, wheat plant, or a mixture of all three of these, in the nutrition of heifers when subjected to the strain of maternity and lactation. This does not prove that similar relations would exist with other species of animals. The experimenters, Messrs. Hart, McCollum and others, were not able to determine the cause of the superior results given by the corn ration.

I cannot conclude this incomplete discussion of the nutritional characteristics of corn without some reference to pellagra. This disease, which is coming increasingly into prominence, has been observed to affect many whose diet consists almost entirely of polenta, a sort of corn-meal mush, and it has been suspected that corn is the cause of the disease. By some it is thought to be the result of consuming unsound rather than unaltered corn products. While the problem cannot be regarded as fully solved yet, and corn completely acquitted from responsibility, there is at present no proof that corn in any form causes the disease.

In connection with the subject of vitamines, or food accessories essential to growth which are not included among the ordinary food principles, it is interesting to note that corn carries both an oil-soluble and a water-soluble accessory. Professor Hughes at the Kansas State Agricultural College has shown that pigeons which had been brought to the last stages of polyneuritis by feeding polished rice or kafir corn may be entirely relieved from the symptoms by administering twenty grains of corn.

The nutritional characteristics of corn have been but imperfectly treated in the foregoing, but it is hoped that enough has been given to show the great variety manifested by these characteristics and the practical importance of scientific interest in them.

American Highways.

J. A. G. Shirk, M. A.

Nothing is a better indication of the degree of civilization attained by any nation than its roads. Many places in Europe and Asia we find yet to-day remains of the great chain of roads built by the Romans. Every block and stone in them is typical of the vigor and strength of the Roman civilization. All these roads led to Rome, so that she might send her armies out quickly to quell any uprising and also that the world's commerce might center in their capital city. In China we find the main roads as mere paths, and thus they have been for centuries, typical of a civilization that is without ambitions or ideals.

Roads are made because there is some imperative need for a means of getting from one place to another. The lower animals resemble man in this particular. Those animals lower down in the scale of life either live upon the food about them, or are carried about by the forces of nature or by larger animals. But as the needs increase, the paths they follow become longer and better defined and we find that there is established what might be termed a highway. In this continent, the best example of permanent animal trails were those made by the American buffalo which led to their feeding grounds, their watering places, and salt licks. The first real thoroughfares of America were probably those made by the big game animals, such as the buffalo. These plunging animals, keen of instinct, moving in vast hordes, broke great roads across the continent along the summits of the watersheds, beside which the Indian trails were mere traces. These roads were swept clear of debris in summer and of snow in winter, so that the early settlers found them of the greatest use in the settlement of the wooded country just west of the Alleghenies. These paths led to the passes through the mountains, and beside the small streams or springs which were good watering places. Along these buffalo trails followed the slow plodding oxen drawing the ponderous wagons of the settlers, and thus the trails were changed into roads, which by fortification and small improvements became the great arteries of travel and traffic between the coast colonies and the settlements and trading posts further west.

The Indians made many trails for purposes of war and peace. Each tribe generally had a hunting ground at some distance from its usual